Geomorphologic Modeling of a Macro-Tidal Embayment With Extensive Tidal Flats: Skagit Bay, WA

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LONG-TERM GOALS

The long term goal of the project is to understand processes affecting morphology changes of muddy tidal flats and provide quantification of the sensitivity of these changes to tidal action, river discharge and shoreline development (e.g., dikes and jetties).

OBJECTIVES

The objective of this effort is to demonstrate the use of a community numerical model for prediction and investigation of tidal flat morphology and forcing parameters. The ONR/Delft community model is being evaluated as a physically-based numerical simulation tool for several investigations, and this effort applies it specifically to tidal flat/channel systems.

Within this objective, the investigators seek to investigate the relative roles of tidal action, river discharge, and shoreline modification on flow over the tidal flats and resulting effects on morphologic modeling. From a model tuning perspective, this objective includes advancing the understanding of the sensitivity of the model to parameter value adjustments and inclusion or exclusion of specific sediment transport processes and characterization in tidal flat and channel systems.

Additionally, the investigators intend to compare model simulation results with observations and use those results for field planning efforts. The model fidelity should be improved by incorporation of observational data for configuration, assignment of boundary and initial conditions, and for calibration and validation efforts. The benefit of using a model to help with the design of the field programs and the interpretation of observational datasets has been demonstrated in other studies (e.g., Hibler et al., 2008).

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APPROACH

A three-phase approach will be used. All phases are model configuration and evaluation intensive. In the first phase the model was configured with best available information. Sensitivity tests were conducted on variations in river discharge discharge to circulation in the Skagit Bay. In the second phase (reported here), adjustments to the model were made to intensify focus in portions of the bay where field activities occurred in 2008 and 2009. Continued incorporation of the observational datasets will enable further model improvement. In the third phase, final model evaluation and the incremental phased improvement assessment will be completed and reported upon.

This work will build upon what has been reported for numerical modeling of geomorphology using Delft3D (e.g., Lesser et al., 2004; Tonnon et al., 2007; van Duin et al., 2004; van Rijn et al., 2007; Marciano et al., 2005). The sensitivity analysis of will focus on bottom type classification (e.g., sediment type) and its impact on sediment transport through bottom roughness parameter variation. Process studies on idealized channels will be conducted as needed.

Both Mr. Lyle Hibler and Dr. Adam Maxwell will conduct model simulations. Lyle Hibler will focus on project management, model experimental design, circulation modeling, reporting and interaction with other program participants. Adam Maxwell will focus on carrying out numerical experiments, sediment transport and morphology, and data visualization and management.

WORK COMPLETED

Work completed since work was the project was initiated (May 1, 2008) includes development of the initial mesh (see Figure 1) and incremental refinements guided by preliminary results and consideration of the sampling plans provided by other program investigators (Dr. Jamie MacMahan at the Naval Postgraduate School, Dr. Britt Raubenheimer at Woods Hole Oceanographic Institute, Dr. Jim Thomson at UW/APL, and Dr. Brett Hooper at Areté Associates).

RESULTS

Anecdotal evidence and other studies (e.g., Yang and Khangaonkar, 2009) indicate that 60-70% of the river flow passes through the North Fork channel, and the present Delft3D model (mesh and bathymetry shown in Figure 1) agrees with this. This division is relatively insensitive to bathymetric modifications in the model, although blocking one of the lower channels of the South Fork will cause a change in flow division.

In order to provide some additional verification of the river flow magnitude and tidal influence, Delft3D drogues (surface layer Lagrangian drifters) were compared with the results of Dr. Jamie MacMahan's field deployment of drifters in the North Fork of Skagit River. Using predicted tides from Xtide (Flater, 2006) and average daily discharge of 240 m^3/s, results were reasonable for the earlier release periods, Figures 2(a)–2(c), particularly for 26 September (Figure 2(a)). In Figure 2(b), it appears that the NPS drifters ran aground at some point, whereas the model drogues followed a deeper part of the channel; actual timing in this case was better than it appears. For the third case, shown in Figure 2(c), agreement between the measured and predicted tracks is quite good. Agreement between measured and predicted tracks is substantially incorrect for the latest period shown in Figure 2(d), however, and the simulated

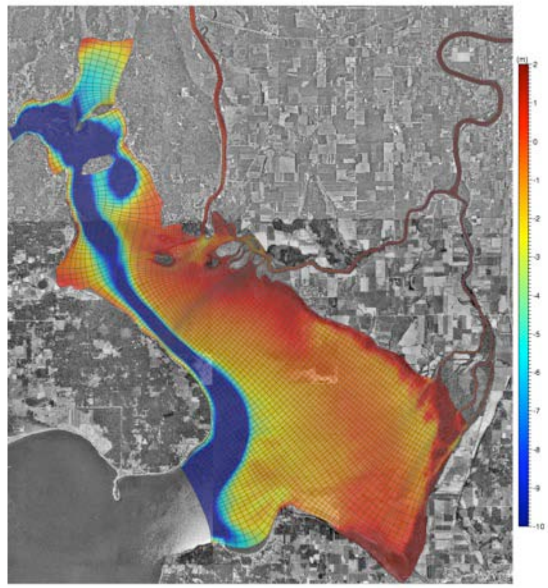
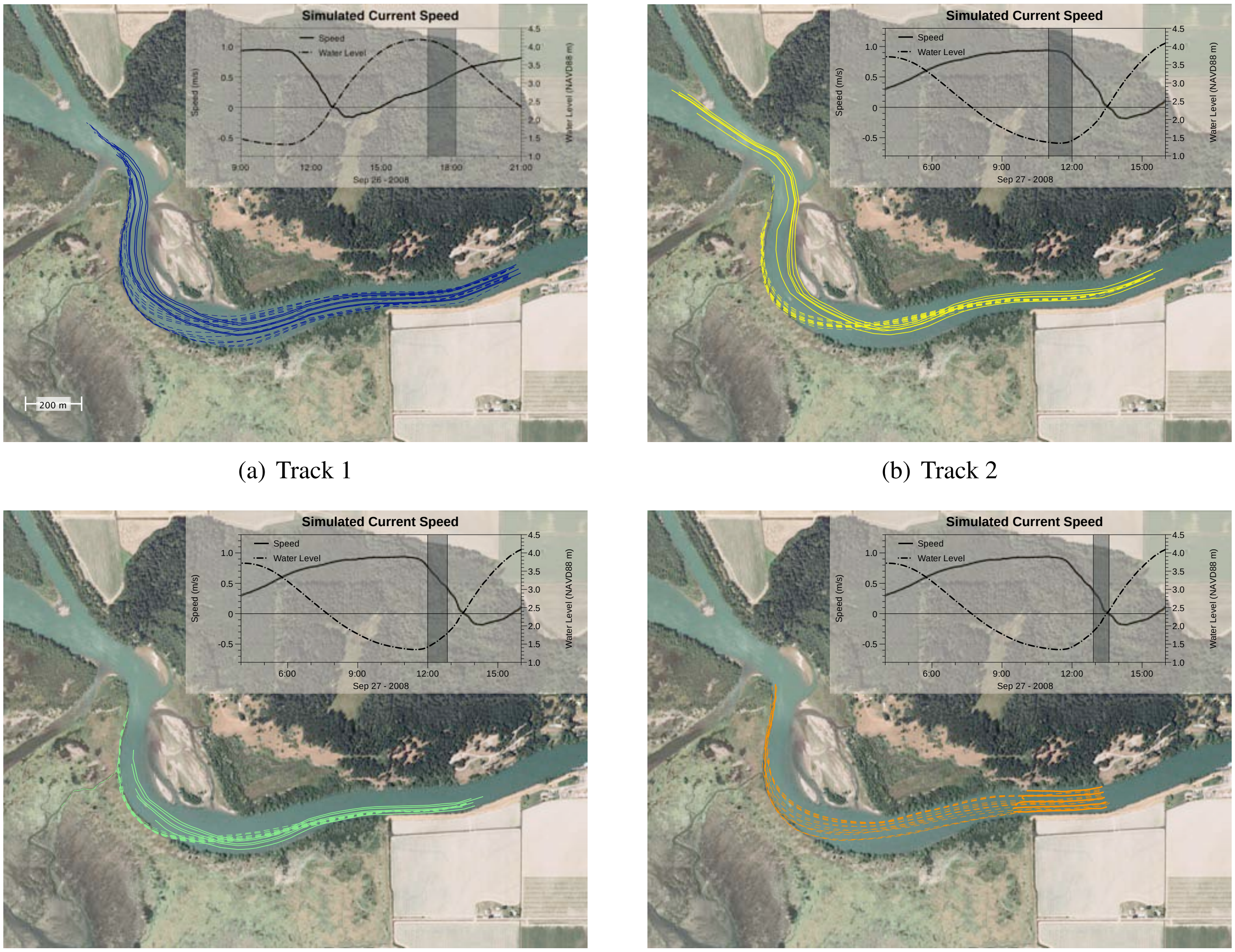


Figure 1: Model mesh and shaded bathymetry, overlaid on a grayscale image. Bathymetry is in NAVD88 meters.

tracks actually show a reversal while the NPS drifters were still traveling downstream. The discrepancy in this last case appears to be at least partially a phase issue with respect to tidal influence in the river; tidal boundary inaccuracies, river bathymetry problems, and hourly variations in river discharge are likely contributing factors. Sensitivity testing is underway to determine the cause of this problem.

Dr. Brett Hooper of Areté Associates provided soundings and shoreline information for the area, taken in 2008 by boat and plane, respectively, and these have been incorporated into the model. Areté also measured surface currents via airborne imaging, and provided flow vectors for comparison. As part of the ongoing sensitivity analysis, surface currents are shown in Figure 3. The incorporation of modified channel bathymetry produced a significant change in surface current speed at the particular time snapshot shown in Figure 3. Qualitatively this appears to have improved the current vector comparison, but corresponding improvements in drogue track behavior were not observed; essentially all tracks decreased in length, so Track 1 agreement improved and Track 2 and 3 agreement worsened. However, it must also be noted that the Areté soundings did not extend the full length of the North Fork, and there are still issues with the channel bathymetry that may be causing problems (Figure 4).

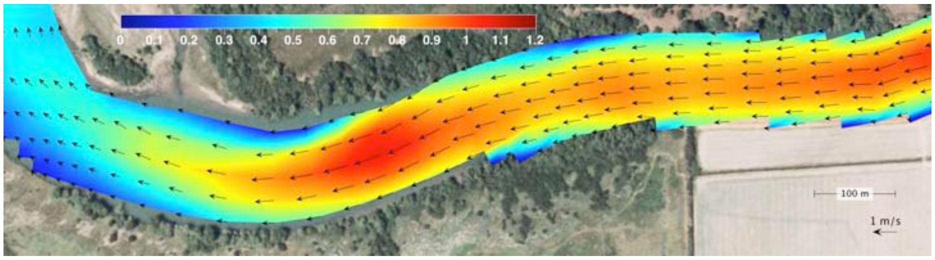
An attempt was made to allow the Delft3D geomorphology module to start from a trapezoidal channel and evolve to a realistic channel geometry by erosion and deposition, but a näive initial condition specification led to significant stability issues in the model. Prof. Dano Roelvink indicated that the Delft3D stratigraphy module should have been enabled, and indicated some possible avenues to explore in resolving this problem (personal communication, March 2009). A simplified scenario with suspended sediment transport only (200 micron sediment) and no bed changes was run for a 7-day time period, in order to demonstrate suspended sediment mixing. The result of this preliminary test is shown in Figure 5, where physically identical sediments were introduced into the North and South Forks; their accumulation in the bed is represented as blue and red, respectively. Qualitatively, this appears to indicate an approximate segregation of sediments, but the North Fork sediment appears to extend to either open boundary of the model; given the greater flow through that channel, this may be reasonable.



(a) Track 1 (b) Track 2

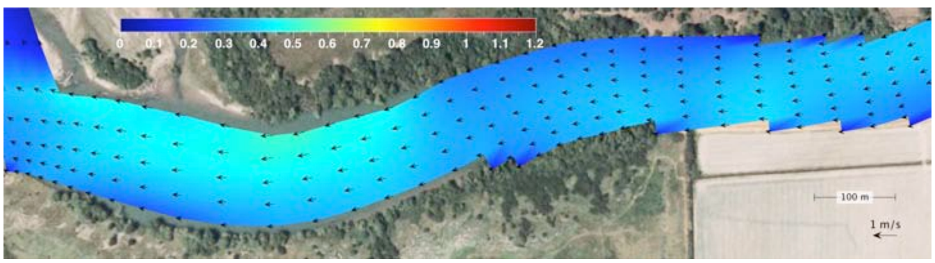
(c) Track 3 (d) Track 4

Figure 2: Comparison of Delft3D drogue tracks with NPS drifter tracks on the North Fork channel. NPS tracks are represented by a dashed line, and simulated tracks by a solid line. The inset figure in each graphic shows the predicted current speed and tidal elevation for each release period as a vertical gray bar.



(a) Predicted surface currents using DEM bathymetry

(b) Areté measured surface currents



(c) Predicted surface currents with revised bathymetry

Figure 3: Comparison of modeled surface currents with remotely sensed surface currents. In the top panel, the simulation used river channel bathymetry based on the digital elevation model (DEM) developed by (Finlayson, 2005). The center panel shows flow vectors from Areté's measurements, and the bottom panel shows simulated currents using improved bathymetric soundings.

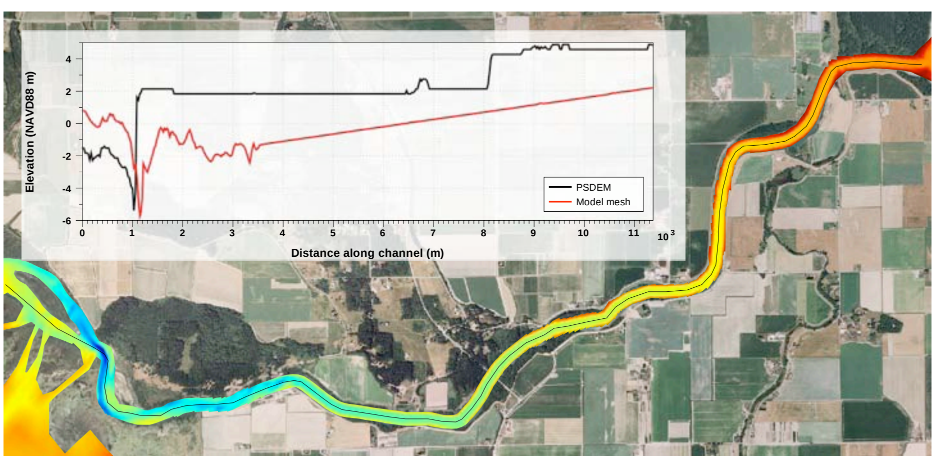


Figure 4: Channel depth shaded, with profile along the centerline of the channel. Inset figure shows the original DEM elevation, and the profile after adjustment and incorporation of Areté's soundings. Note the >2 m drop in the DEM channel, which caused significant model instability.

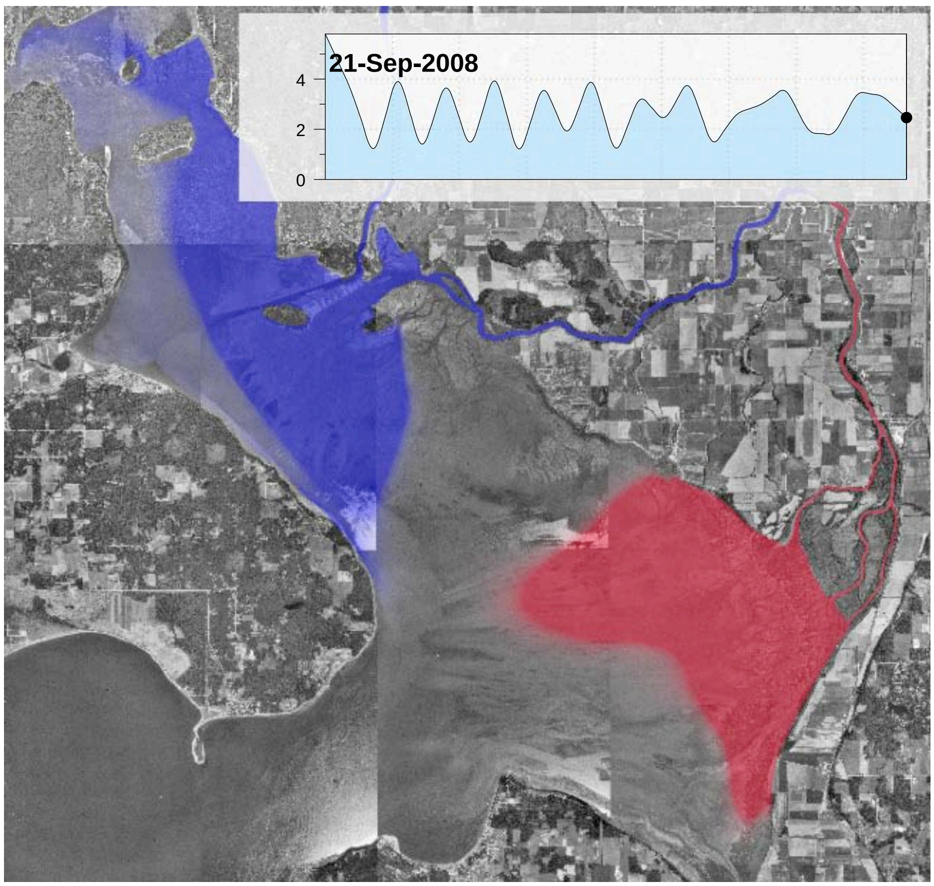


Figure 5: Preliminary graphic showing deposition of previously-suspended sediment from the North and South Fork of the Skagit River. Sediment from the North Fork is shown as blue, and sediment from the South Fork is shown as red.

IMPACT/APPLICATIONS

The impact from this work will be further evaluation of the ONR/Delft community model for geomorphological simulation in an environment that is of interest to the Office of Naval Research and in DoD-Navy, where the software is already being used for other applications. Sensitivity analyses produced in this study will be useful in assessing the data requirements for simulation in data-limited areas. This study has also demonstrated methods for integration and comparison of remotely sensed and *in-situ* measured data with simulated data for assessment of model performance.

RELATED PROJECTS

Modeling work is concurrently being done to support a program entitled Observations and Modeling for Source Characterization (N000140810508) with Dr. Mark Moline (http://www.marine.calpoly.edu/auv/), Dr. Eric Terrill at Scripps Institution of Oceanography, and Dr. Ap Van Dongeren at WL—Deltares. Lyle Hibler and Adam Maxwell will be using the same numerical modeling software to investigate the circulations Southern California coast with focus on San Diego Bay and the Tijuana River under subcontract to California Polytechnic State University. Integration of modeling efforts with observational datasets will be the focus of this effort.

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